# Fast, Space Qualified 3000 V Modulator for a Cloud Profiling Radar

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**Abstract**

Cloudsat's Cloud Profiling Radar (CPR) delivers a 2 kW, 94GHz of RF energy pulse using a High Power Amplifier (HPA) consisting of a High Voltage Power supply (HVPS) and an Extended Interaction Klystron (EIK). To drive such an EIK, it was necessary to develop a -16.3 kV High Voltage Power Supply (HVPS) and a Focus Electrode Modulator (FEM), floating at Cathode potential to turn the EIK's Beam on (-45V) and Beam off (-3kV) with respect to the Cathode. This paper describes the design approach for the FEM and its performance in EM and Flight configurations. This design is a simple but universal approach which allows the designers to greater flexibility and freedom in designing high swinging voltage space- qualifiable FEM.

**Introduction**

This paper describes the development of a fast 3000 V Focus Electrode Modulator (FEM) to drive a 2 kW, 94 GHz, pulsed Extended Interaction Klystron as part of a High Power Amplifier (HPA-Figure 1), used in the Cloudsat Profiling Radar (CPR), which is due to launch in June of 2005. This will be the first Radar instrument to fly in space at this power, operating voltage and high speed 3kV FEM (rise and fall time of less then 200 nanoseconds). The EIK was developed by Communication & Power Industries of Canada (CPI) and papers have been published (ref 1, 2)

The Modulator floats at a cathode potential of -16.3 kV and the modulator, when in cut-off, is -3.0 kV with respect to cathode. FEM output is at -45V with respect to Cathode when the beam-on state.

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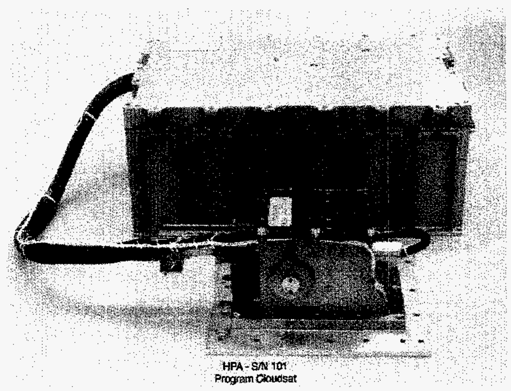


Figure1: Cloudsat High Power Amplifier

The challenge was the containment of extreme high voltage (-20 kV) and as well as high slew rate (15 kV/μsec.) of modulator voltage and retain the rise and fall times without any special screening of any part. There are many ways of achieving the performance, but JPL selected a Push-Pull arrangement using four (4) appropriately de-rated high voltage FETs in series in each of the Push/Pull stage (referred to as a four stage Modulator).

For the Flight units, the design had to be modified to a 10 stage configuration (10 each in each for Pull and 10 each for the Push stage) due to orbit-dictated radiation environment and tests of flight FETs. Both four stages and ten stages Modulator has met their environmental, thermal vacuum tests and burn-in requirements.

**Basic Electrical Design**

Figure 2 below shows a generic Block Diagram for the Focus Electrode Modulator (FEM). The A5 (Pull-up) and A6 (Pull-down) block each contain four or ten series FETs.

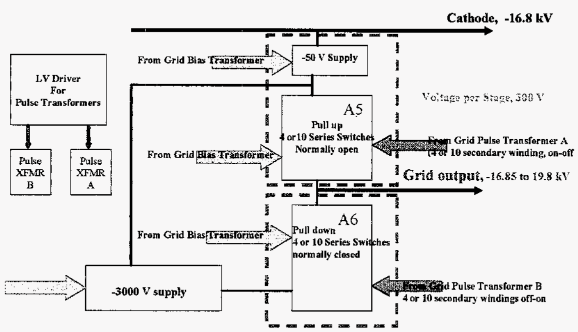


***Figure 2:*** ***Generic Block Diagram (4 or 10 Stages)***

The basic top level layout (not to scale) of the FEMs elements is shown in Figure 3. Power Processor is not part of FEM.

The A5 stages are designed such that in absence of Pulse Command the output FETs are biased negatively with respect to their sources. The A6 stages are biased on. Each stage has its own bias network and a gate drive circuit, driven by four (4) or ten (10) secondary windings of the pulse transformer. A5 Pulse transformer (A) is out of phase with A6 pulse transformer (B) and are driven by a pulse shaper at low voltage deck.

The pulse transformers are designed to minimize capacitance to primary winding and equalize capacitance between secondary windings and maximize coupling to the primary

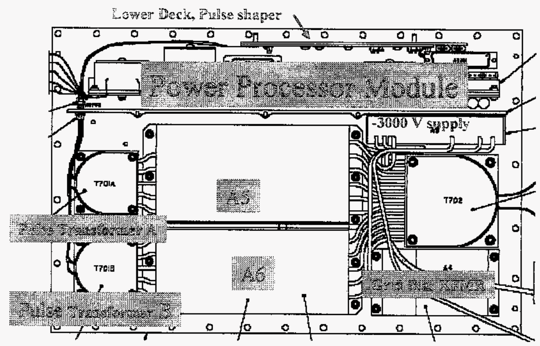


**Figure 3:** *Basic FEM layout for Flight Units*

This approach insures that the driving pulses are within 5 nanoseconds of each other. With this approach each stage is actively driven on and off to insure the output stages are turned on and off and the voltage division between stages remains equal in transitions and in steady state. In the off mode each FET has equalizing shunt resistors to account for the variation in leakage current over life and temperature. The above was, in part, verified by PSpice® simulation. Data shown in Table 1 and Figure 4 is for a four stage FEM and shows the rise and fall time are well within the limits of desired performance.

**Table 1: EM Test data (4 Stage per FEM)**

| Temperature, C | | -20 | 25 | 55 | 70 | Req. |
|---|---|---|---|---|---|---|
| Grid On | Volts | -53 | -34.83 | -35.1 | -35.4 | |
| Grid cutof | volts | -2839 | -2845 | -2807 | -2809 | |
| Grid Dela | nano sec | 500 | 525 | 552 | 544 | |
| Grid Rise | nano sec | 170 | 147 | 178 | 180 | 200 |
| Grid Stota | nano sec | 750 | 800 | 854 | 889 | |
| Grid Fall | nano sec | 50 | 73 | 72 | 41 | 200 |

The delay is cased by the pulse shaper on the lower deck

*Note*: Breadboard and EM utilized a four (4) stage and Flight unit utilized a ten (10) stage design.

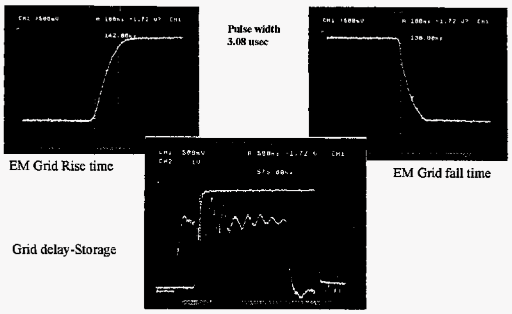


Figure 4: The Grid Rise, fall and delay

**Containment of High voltage and high slew rate.**

High voltage designers are fully cognizant of the dangers of high electric stress, presence of corona and temperature. In this design care was taken to insure that the assemblies were corona free at or above the operating voltages and electrical stress, and temperatures were consistent with the 12 year design life.

Figure 5 shows the flight configuration of the FEM. There are six cards for A5 and five cards for A6. The 6th card in A5 card is dedicated to the Focus electrode ON voltage. Each of the cards in A5 and A6 contain two stages. Therefore the maximum potential between any two cards is less then 600 Vdc.

The uniqueness of the design is that the back side of the assembly is at a uniform potential, but and the stages are separated by 600 V (worst case). It also important to note that A5 and A6 components are pointing inwards so that the end assemblies sit at

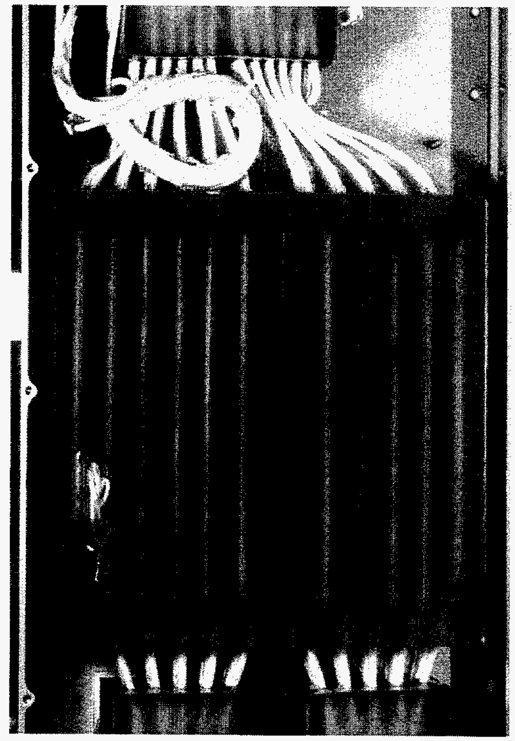

Figure 5: Flight Configuration of FEM

-20 kV or -16.3 kV. A5's outside card always remains -16.35 kV (Focus electrode -45 plus Cathode potential). In addition, the edges are rounded as can be seen in figure 5 and 6, to minimize edge effects. Figure 6, shows the voltage

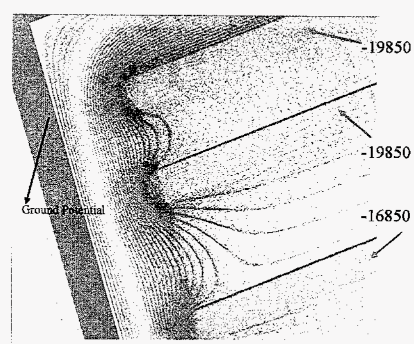


Figure 6: Voltage distribution across FEM

distribution, Individual Assemblies and final assembly are corona free at operating voltages.
Further, it was important to maintain reasonable temperature rise and profile. The results are shown in figure 7.

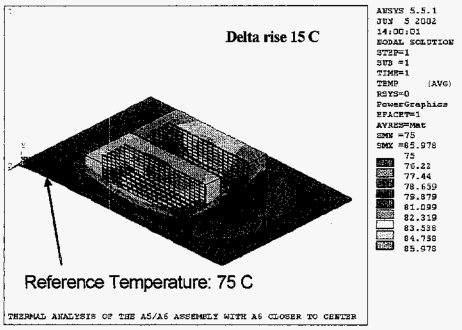


Figure 7: Temperature rise profile

**Test Data.**

Testing to date includes a large number of deliberate and accidental shorts at ambient pressure and vacuum, with and without the EIK (Extended Interaction Klystron). The FEM did not experience failure and the performance remained within requirements as shown in Table 2 and Figure 8.

Table 2: Flight HPA 101, FEM data

| Temperature HVPS/EIK Deg C | RF Delay nana sec | RF Rise Nano sec. | RF Storage Microsec | RF Fall time Nano Sec. |
|---|---|---|---|---|
| 33/50 | 928.0 | 62.0 | 1.050 | 18.0 |
| | | | | |
| 25/35 | 980.0 | 57.0 | 1.080 | 22.0 |
| | | | | |
| 0/20 | 922.0 | 50.0 | 1.020 | 28.0 |
| | | | | |
| -20/-15 | 910.0 | 49.0 | 0.950 | 14.0 |
| | | | | |
| -15/5 | 902.0 | 52.0 | 1.004 | 14.4 |
| | | | | |
| 10/15 | 920.0 | 54.5 | 1.039 | 22.0 |
| | | | | |
| 25/25 | 948.0 | 59.0 | 1.084 | 25.0 |
| 23/23 | 888.0 | 52.0 | 1.000 | 22.6 |

**Conclusion.**

It is clear that EIK's requirement of 200 nanoseconds for rise time and fall times has been met over the specified

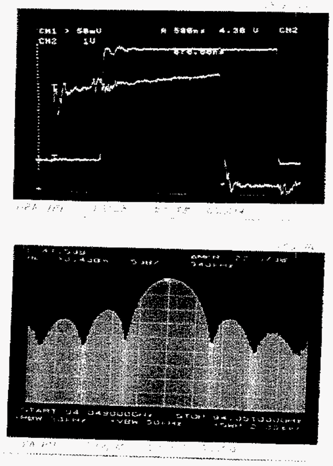

Figure 8: FEM Command, RF output and Spectrum in TV

Environment, and data collected is within the CPR requirement and performance is very satisfactory.
When launched, it will be the first such instrument in orbit to deliver 2 kW of RF power in with such a fast FEM.
This approach to the design is adaptable to any range of voltage swings (excursions) if attention is paid to the pulse transformer design and selection of FETs.

**References**

[1] Brian Steer et al., "The CloudSat Extended Interaction Klystron", 2nd IEEE International Vacuum Electronics Conference 2001, Noordwijk, The Netherlands, 2-4 April 2001

[2] Dave Berry, Albert Roitman and Brian Steer, "State-of-the-Art W-band Extended Interaction Klystron for the CloudSat Program" 5th IEEE International Vacuum Electronics Conference 2004, Monterey, California, 27-29 April 2004